Corona-electrospinning: An Efficient Needleless Method for Producing Nanofibers

Kolos Molnár[1,2*], Zsombor Kristóf Nagy[3]
[1]Budapest University of Technology and Economics, Faculty of Mechanical Engineering, Department of Polymer Engineering, Műegyetem rkp. 3., Budapest, 1111, Hungary
[2]MTA-BME Research Group for Composite Science and Technology, 1111 Budapest, Műegyetem rkp. 3, Hungary
[3]Budapest University of Technology and Economics, Faculty of Chemical Engineering, Department of Organic Chemistry and Technology, Budafoki út 8., Budapest, 1111, Hungary
*molnar@pt.bme.hu

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INTRODUCTION

Electrospinning has gained a high interest in the last two decades as it is a simple method that allows producing nanofibers [1]. The process can be cost-effective, as there are a few companies who produce nanofibers already. Application of nanofibrous materials can be realized in filtration masks or HEPA filters, protective or military clothing, etc. [1-3]. At classical electrospinning a polymer solution is fed through a metal capillary which is connected to a high voltage power supply. A counter-electrode, that is usually grounded, is also applied and named collector. The fibers are formed by the electrostatic forces acting on the liquid deforming that [4].

Although electrospinning is quite simple, it is still a big challenge to increase the productivity of the process. One capillary typically has an output between 0.1 and 5 ml/h, depending on the solvent, polymer and different additives. The produced fibers typically have a mass flow of one order of magnitude smaller as the solvent has to be evaporated.

The simplest way to increase the productivity of electrospinning is the multiplication of the needles, but that leads to feeding issues, clogging of the capillaries and different cleaning and maintenance problems. The emerged difficulties relating to the needles can be avoided by using needleless electrospinning methods which are quite popular nowadays [5-9].

Electrospinning from a free liquid surface without using a needle is possible if the gradient of the electric field is high enough at the liquid surface therefore the jet forming forces and tensor stresses can overcome the surface tension of the solution. Several types of needleless fiber spinnerets have been developed for increasing the productivity of nanofiber manufacturing. Maybe the most popular one is Nanospider™ technology [5], where a rotating cylindrical electrode is submerged into the electrospinning solution bath and nanofibers are evolving from the liquid layer formed on the surface of the cylinder.

The main drawback of the needleless methods is the occurrence of a relatively large free liquid surface (at polymer solution reservoir, at rotating cone taper, etc.) where besides jet formation other, undesired processes can take place such as water vapor absorption, solvent evaporation and in extreme cases ignition, too.

Thus the aim was to develop an electrospinning method which is capable for high throughput production of nanofibers and suitable to use volatile solvents to meet the requirements of the pharmaceutical industry. The novel technology [10] offers continuous mode with high throughput and a simple, easy-to-maintain needleless spinneret construction operating without free liquid surface hence minimizing the solvent evaporation therefore nanofibers can be produced from not just high but low boiling point solvent based solutions as well.

APPROACH

The main idea of the spinning system is to continuously supply the polymeric solution through a narrow, but long gutter bounded by a metal electrode having sharp edge. The highest electrical charge density is formed along the sharp edge resulting many self-assembled Taylor-cones. The rotating spinneret construction makes possible to apply high electric field directly at the locations where Taylor-cones are formed leading to efficient and high-throughput nanofiber production. The concept of the *corona*-electrospinning method can be seen in Figure 1.

The solution is fed through a hollow shaft having appropriate roller bearings and sealing to avoid the leakage. In the upper part the solution is distributed along the thin gutter (between part 2 and 5). The cylindrical metal electrode (other shapes can also work) have a sharp edge for charge concentration. The lid (part 5) can easily be removed for cleaning. The spinneret is connected to a high voltage power supply and the generated nanofibers can be collected on a grounded collector screen or on a textile substrate.

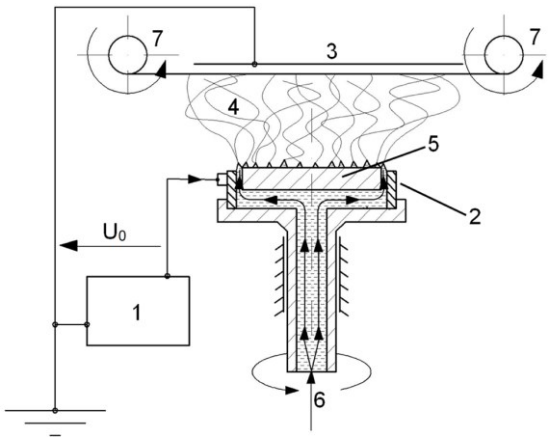

Figure 1. Schematic figure of the *corona*-electrospinning setup. 1: high voltage power supply, 2: circular electrode having sharp edge, 3: grounded collector screen, 4: fiber formation space, 5: lid, 6: solution feed, 7: traction of the collector textile

RESULTS AND DISCUSSION

The working prototype having 42 mm electrode diameter can be seen in Figure 2. The applied model material was a solution of polyvinylpyrrolidone (PVP) dissolved in ethanol. The small spinneret could reach a productivity up to 200 ml/h fed by an Aitecs (Lituania) type syringe pump.

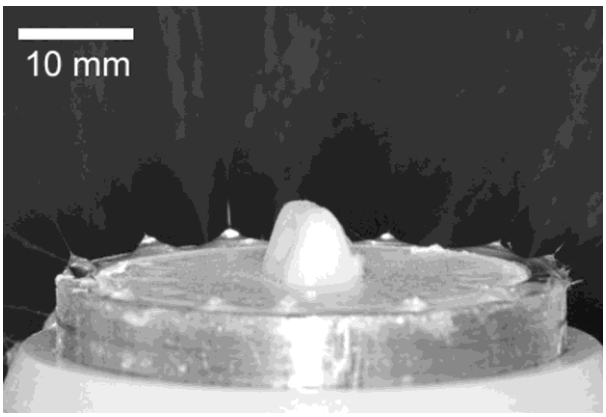

Figure 2. Taylor-cone formation along the round metal electrode of the spinneret

The formed nanofibers had a diameter of around 200 nm and no significant difference could be observed between these fibers and the ones generated by single capillary method.

During the process rotation helps to uniformly distribute the solution. The nanofibers are ordered in even distances and as there is Coulomb-repulsion between them they diverge from one another. This leads to a shape that looks like a traditional crown hence we named our method *Corona-electrospinning*.

CONCLUSIONS

A novel needleless method which offers high productivity nanofiber formation was introduced in this work. The process works without open liquid surface and the solution flows continuously eliminating the problems of other needleless methods.

The designed rotating spinneret prototype is a simple construction, easy to clean and maintain and furthermore the technology can easily be industrialized. The cones of the solution evolving along the circular gutter leads to a crown-shaped nanofiber generation. The productivity could reach 200 ml/h which is 2 orders of magnitude higher than that of a single capillary method.

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